Analysis of Hyperspectral Data for Coastal Bathymetry and Water Quality

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LONG-TERM GOALS

Our long-term goal is the development of spectral analysis tools that fully exploit the information content in hyperspectral image data, particularly as it applies to remote sensing of ocean color and the extraction of bathymetry, water quality and bottom type information.

OBJECTIVES

Our objectives are to develop specific algorithms and procedures to classify water types, differentiate among different bottom types and extract bathymetry from passive hyperspectral image data. When the water type and bottom reflectance are uniform over the study area, bathymetric mapping with passive remote sensing data is a relatively straightforward, one-variable problem and requires a minimum of field data. It is even possible to extract a relative water attenuation coefficient from spectral image data. The problem quickly becomes much more complex when the water type and bottom type vary over the scene. In that case, the depth cannot be determined without simultaneously resolving the bottom reflectance and basic optical water properties. Bathymetric mapping is thus an inherently multivariate problem requiring at least several spectral bands. We expect that effective use of hyperspectral image data will lead to significant improvements in the accuracy and detail of the results.

APPROACH

Our approach has several components.

1) One component involves inverting a simple two-flow radiative transfer model (Philpot, 1987; Philpot, 1989). While the simple model may not be able to characterize the full range of in-water optical properties, we expect it to be an adequate representation for remote sensing applications in many, if not most, situations. Initially the effort relied entirely on synthetic data. We have since progressed to using in situ observations and are in the process of implementing procedures that would be used with satellite or aircraft imagery. (David Kohler)

2) A second component involves radiative transfer modeling using the full radiative transfer code provided by HYDROLIGHT (Mobley, 1994). In this task, the focus has been on building a spectral library of inherent optical properties (IOP's) for each component of the water (pigments, dissolved organics, particulates, etc.). The modeling includes the shape, morphology and size distribution of the individual phytoplankton taxa as well as the vertical distribution of each water

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14. ABSTRACT

Our long-term goal is the development of spectral analysis tools that fully exploit the information content in hyperspectral image data, particularly as it applies to remote sensing of ocean color and the extraction of bathymetry, water quality and bottom type information.

15. SUBJECT TERMS

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component. Particular effort is being made to model the specific scattering phase functions and the interaction of scattering and absorption for particles of different sizes and morphologies. The resulting IOP's are used as input to HYDROLIGHT to predict the spectral water-leaving radiance given a specified vertical distribution for each component. The intent is to provide a tool for evaluating the sensitivity of the water-leaving radiance to changes in the IOP's and their distribution in the water column as well as to determine changes in illumination. The predicted water-leaving radiance may also be matched to measured water-leaving radiance. (Minsu Kim)

3) Finally, we are applying a spectral-spatial image analysis procedure both to support the hyperspectral inversion procedure, and improve the identification of different bottom type. The hyperspectral image is first spatially-spectrally smoothed using a modified edge-preserving smoothing algorithm. The smoothed image is then segmented into clusters of similar spectral character. The segmented image (with spectra that are averaged in the spatial domain) may then be used to provide low-noise input to the inversion procedure. Finally, individual clusters may be assigned a specific bottom type based on spectral matching with a library of known bottom-type reflectances. (Bruce Monger)

WORK COMPLETED

1) A software package, HYPERSPEC, designed to facilitate the computation of spectral derivatives has been completed and distributed to interested PI's.

2) A second software package, Ocean Optics Plankton Simulator (OOPS) has been developed and made available to interested PI's (http://otto.cee.cornell.edu/). This is a visual, interactive tool to facilitate the investigation of the effect of changes in IOP's and their vertical distribution in the water column on the water-leaving radiance. An advanced version of the software package now includes computations of the full spectral scattering phase function for particles with a range of shapes, and morphologies. The most recent version includes the capacity to model bubbles within a limited size range.

3) We have developed a method to derive water depths from remote hyperspectral imagery based on parameters derived from a set of in situ hyperspectral observations (AOP's). The procedure begins with a correction of the HyperTSRB measurements for the depth of the upwelling radiance sensor. The corrected values for upwelling radiance can then be used to derive several spectral parameters that are the basis for optimizing the depth. These are the spectral radiance due to the presence of the reflective bottom, L_b, the deep water radiance, L_∞, and an effective spectral attenuation coefficient, g.

4) A procedure for estimating atmospheric path radiance in remotely sensed imagery has been developed. The procedure utilizes a single-scattering model fed by in situ measurements. With the assumptions of a locally uniform in-water diffuse attenuation coefficient and a locally uniform atmosphere, we are able to estimate atmospheric path radiance over regions of constant bottom type based on deviations between model prediction and remotely observed changes in radiance that occur with changes in bottom depth.

5) The IDL software code that performs edge-preserving smoothing has been completed. The underlying theoretical approach for software development of the clustering algorithm has been established and is expected to be coded within the next month. Assigning spectral clusters to specific bottom types is still in theoretical development.

RESULTS

Bathymetry, water quality and bottom type: The procedure for extracting water depths from remote hyperspectral image data is essentially an optimization procedure that solved for the unknowns in a two-flow radiative transfer equation using a limited number of known depths. In optically shallow waters, the spectral variations of reflectance are most sensitive to changes in bottom depth and least sensitive to the bottom albedo. Thus the results of the conversion procedure are typically most reliable for the depth estimate, and least reliable for the bottom albedo estimate. However, if the water type and bottom depth are either invariant or well know, changes in bottom type become apparent. As an example, inversion for spectral data crossing a grass bed surrounded by sand in a gently sloping area adjacent to Lee Stocking Island (Figure 1a) where the water type was invariant, two independent procedures (Principal Components and Derivative Analysis), produced significantly different depth predictions over the grass when assuming a bottom reflectance for a coral sand bottom (Figure 1b, c).
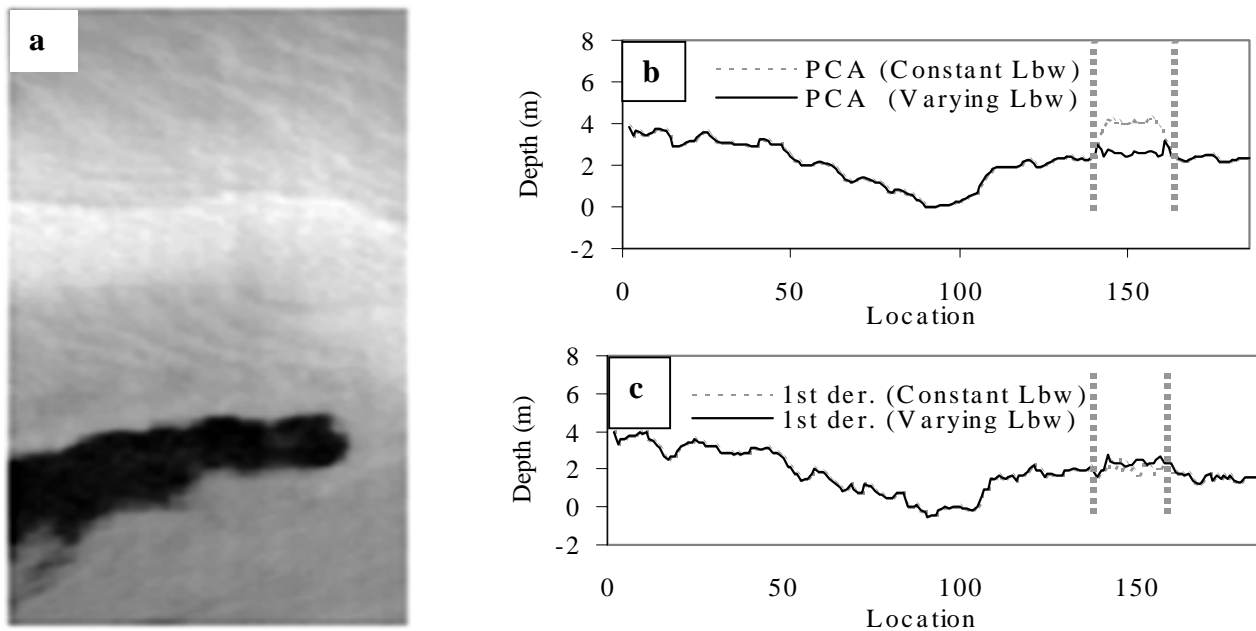

Figure 1. Bottom depth and type.
a) Grass bed (dark area) surrounded by coral sand bottom.
b) Principal components results: Retrieved depth over grass bottom changes abruptly
when the bottom reflectance is assumed to be constant.
c) Derivative analysis results: Depth retrieval is not sensitive to bottom type.

While the retrieved bottom reflectance was not terribly realistic, the predicted reflectance changed significantly over the grass bottom. The reflectance on opposite sides of the grass bed also appeared significantly different, a result that could only be corroborated indirectly by correlation with a bottom type classification (Louchard, 2000).

Phytoplankton Optical Model: OOPS computes the scattering, absorption, and scattering phase function based on the size distribution, cell morphology and complex refractive index of the component plankton species and includes the contribution of CDOM, suspended particles and bubbles.

The unique pigment composition of each taxa is the most important optical factor for discriminating among taxa. However, the intensity of the scattering and its angular pattern also affects the water-leaving radiance.
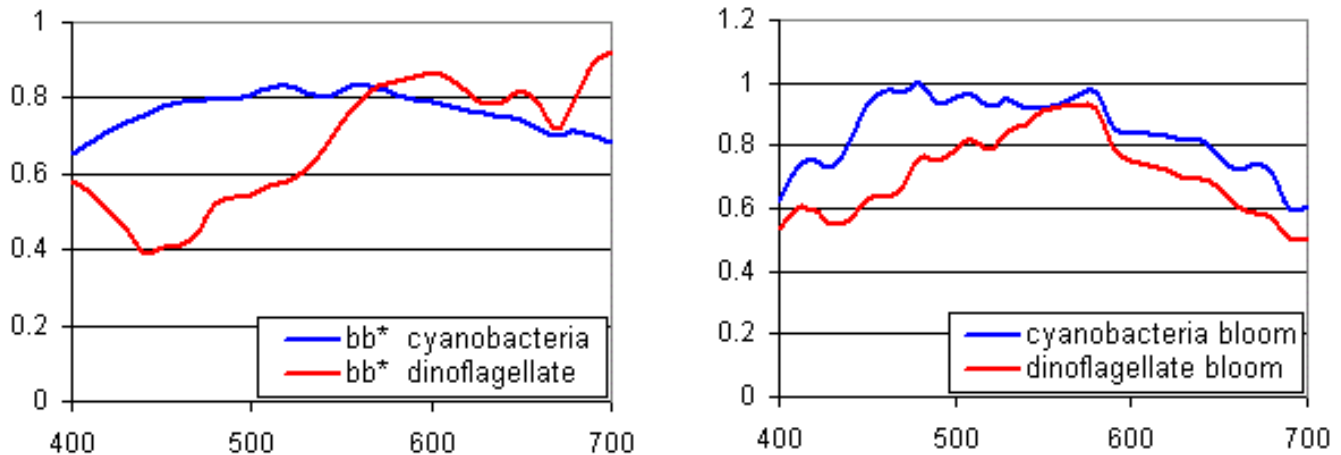

Figure 2. Comparison of backscattering and water-leaving radiance from two taxa showing the spectral differences when the magnitude of the backscattering and chlorophyll concentration are similar: a) Backscattering cross-sections, b) Water-leaving radiance

A simulation carried out using two different types of algae, cyanobacteria (Synechococcus) and dinoflagellate (Amphidinium Carterae) shows that the computed spectral backscattering cross-sections are significantly different for the two algae due to their pigment compositions, size, and the shape Figures 2.

Image segmentation:

Edge Preserving Smoothing (EPS) has been described elsewhere for the case of a single spectral band image (Nago & Matsuyama 1979). The same general procedure is used, but instead of determining the average and variance of a single band intensity the average spectra is determined and the total variance about the average spectrum is computed. The spectrum of the central pixel is assigned the averaged spectra of the pixel block containing the lowest total variance. As a result, spectral averaging never crosses abrupt spatial changes in spectral intensity or spectral shape. In the following example, a PHILS image taken over Lee Stocking Island (LSI) was processed using every third spectral band between 415.9-nm to 658.6-nm for a total of sixteen. For test purposes the program was run for just thirty iterations. The images (Figs. 3a,b) depict band twenty-one (λ= 479.5 nm) before and after the spectral EPS processing.
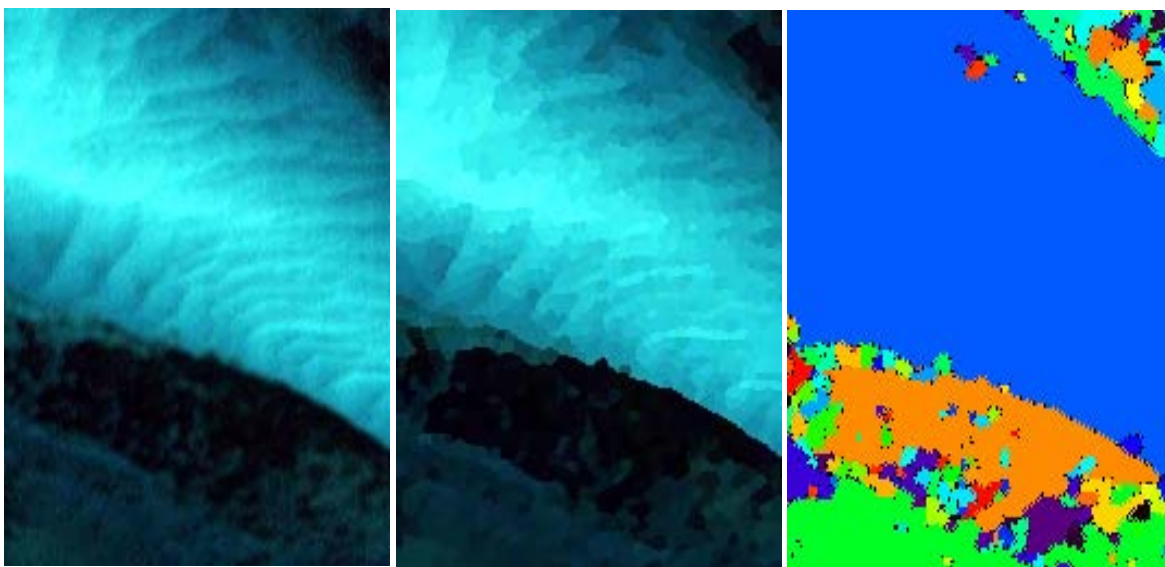
Figure 3. a) Original image, λ=479.5 nm; b) smoothed, segmented image, λ=479.5 nm; c) result of spectral region growing applied to the segmented image. The segmented regions represent spectral changes that are not consistent with spectral variation typical of changes in depth.

An approach for clustering regions of similar bottom types has been developed that uses a modified region growing approach. Initial pixels are systematically selected in an image and then grown larger by incorporating pixels having similar bottom types. Change in spectral shape between two adjacent pixels is compared against spectral change predicted for a depth change of similar bottom. If the observed spectral change between pixels does not deviate significantly from that expected for a depth change, the bottom-types of the two pixels are considered to be the same and incorporated into the unique local area group. If the observed change deviates significantly from that expected for a depth change, the adjacent pixel is labeled as a separate bottom type and this new bottom-type pixel is then grown as a new local area by looking at other adjacent pixels and using the same bottom type matching approach. Fig. 3c depicts the results of a very preliminary test of this region growing procedure for the LSI image.

IMPACT/APPLICATIONS

Bathymetry, water quality and bottom type: The procedure developed during this project makes full use of the hyperspectral data available and achieves good, stable results for bathymetry. The optimization is applied simultaneously for depth, an effective spectral attenuation of the water and bottom albedo. There is still a need for seed information about the target area, e.g., a sampling of known depths, however, the procedure (combined PC and derivative analysis) appears to be capable of detecting changes in bottom type at least where water quality is uniform over that change.

Phytoplankton optical model: The accurate computation of the scattering, absorption, and scattering phase function of the water provided by OOPS has significant implications for remote sensing of ocean optics. For example, preliminary computations of water-leaving radiance suggest that it may be possible to improve the accuracy of the chlorophyll concentration by first categorizing the phytoplankton taxa. The implication is that different taxa have significantly different effects on the

spectral quality of the water-leaving radiance and must be treated differently if one is to retrieve the chlorophyll concentration with accuracy.

Image segmentation: The concept of segmenting a hyperspectral image was to assist the bathymetric analysis by first grouping pixels that are spectrally similar and then tracing the spectral changes in adjacent groups. The segmentation procedure is unique in that it operates in the hyperspectral domain whereas most segmentation procedures are designed to operate on monochrome images. This has implications for classification and analysis of hyperspectral imagery.

TRANSITIONS

1. Our program for processing HTSRB data has been used by other PI's in ONR's CoBOP program and has been incorporated into the newest version of software by Satlantic.

2. OOPS has been made available to other investigators in the HyCODE and CoBOP programs.

3. TSRB data from LIS 1999 and 2000 and for LEO 2001 has been provided to WOODS. TSRB data for the LEO 2001 experiment has been shared with Bob Arnone, Joe Rhea and Gia Lamela

RELATED PROJECTS

None

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